RO/hk 021370US   - 1 -
September 8, 2003

METHOD FOR MEASUREMENT OF OPTICAL OR ELECTRICAL SIGNAL SEQUENCES AND EYE DIAGRAM MONITOR FOR MEASUREMENT AND DISPLAY OF SIGNAL SEQUENCES

BACKGROUND OF THE INVENTION

The present invention relates to a method for measurement
of optical or electrical signal sequences in an optical
or electrical transmission system wherein a multitude of
consecutive signals are periodically sampled at a
specific sampling time with one or more adjustable
threshold values. In addition the present invention
relates to an eye diagram monitor for generation of an
eye diagram representation of a signal sequence with at
least one threshold decision circuit, at least one
storage device, and an analysis device.

In communication systems signals rsp. signal sequences
are transmitted via optical or electrical transmission
links. Accordingly transmission links are qualified as
optical or electrical links. Both types of links have in
common that on its way from transmitter to receiver the
signal sequence is degraded by different effects, in
particular attenuated and distorted, so that the signal
at the receiver differs from the signal at the
transmitter. In order to avoid errors in the transmission
of signal sequences it is necessary to process the
received signal in such a way that in the receiver the
correct signal sequence is identified.

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Since several years optical fibers have been increasingly utilized for signal transmission at high data rates over long distances. Besides attenuation, noise and other effects, dispersion limits the maximum data rate and maximum transmission distance of an optical link. With increasing data rates and transmission distances signals are stronger distorted, so that appropriate signal processing is required in order to recover the original signal sequence from the received signal and to avoid errors during transmission.

Compensation of distortion especially caused by dispersion can be achieved in the optical domain as well as in the electrical domain, e.g. by pre-distortion of the signal in the transmitter and post-processing of the signal in the receiver. At low data rates this can be done statically, e.g. by

cascading different types of optical fiber with different dispersion coefficients or by means of dispersion compensated fiber or by one-time adjustment of electrical or optical filters. At high data rates static compensation is not sufficient because dispersion effects can be time-variant. Especially temperature, pressure, and torsion changes rsp. vibrations can result in time-variant dispersion so that dynamic dispersion compensation is required.

Through dispersion effects, such as e. g. polarisation mode dispersion or chromatic dispersion, distortion of the signal occurs which is caused by overlapping signal components with different polarisation modes or wavelengths. The different signal components propagate

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with different velocities in the optical fiber so that
the signals arrive with diffuse timing at the receiver.
In order to separate different signals at the receiver
which are superposed caused by dispersion effects dynamic
equalization is required wherein optical or electronic
filters are adjusted dynamically.

For dynamic filter adjustment a decision is required
whether the adjustment yielded a signal quality
improvement or degradation. This can be achieved by means
of a comparison between target data and actual data which
can be obtained e. g. by means of error correction at the
receiver.
In the beginning it has been stated that the invention
pertains to a method for measurement of optical or
electrical signal sequences. Whether one refers to a
signal sequence as being electrical or optical depends on
where the signal sequence is looked at in the system.
Usually in the transmitter a signal sequence is
electrically generated which is then converted into an
optical signal and fed into the optical link, i. e.
optical fiber. For recovery of the distorted and
attenuated signal sequence which has been transmitted the
optical signal is converted into an electrical signal.

Afterwards, data recovery is usually done by means of a
clock and data recovery device (clock and data recovery
module, CDR) which samples the signal sequence at an
„optimum" time and stores the sampling result in a
digital memory cell until its next sampling point. As a
result, a data signal virtually without time and
amplitude noise is available. For the identification of
the optimum sampling point two clock and data recovery

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devices can be operated at different sampling points
wherein the better signal can be used for data recovery
and the sampling point of the other clock and data
recovery is varied to find the optimum sampling point.
However, this technique is applicable only if the signal
is of sufficient quality so that it is ensured that the
chosen sampling point is near the optimum sampling point.
If distortion of the received signal is too high an
assessment of the signal quality is necessary beforehand.

According to the state of the art direct measurement of
signal quality of optical transmission systems is often
done by measuring the eye diagram. The eye diagram is a
very good means to identify errors of certain components
of a transmission system and to make a quality assessment
of the performance of the system. The eye diagram is
constructed by overlay of similar signal sequences on the
screen of an oscilloscope.

According to the state of the art for fast signal
measurement usually an analog sample-and-hold circuit is
used which is followed by an analog-to-digital converter.
With this measurement an eye diagram representation can
be constructed similar to the oscilloscope. The sample-
and-hold circuit is required because the analog-to-
digital converter is in the order of magnitudes slower
than the signal which is to be measured and requires a
constant input signal. The sample-and-hold circuit
consists of a storage element, usually a capacitor, and
an electrical switch which is closed for an extremely
short time interval so that the storage element is set to
the value of the currently measured signal.

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With increasing transmission rate the use of a sample-
and-hold circuit becomes challenging. With the time-
window for the acquisition of the sampling value
shortening and a maximum limit for the charge current the
capacitance of the storage capacitor has to decrease. At
data rates of up to 10 Gb/s and more, especially at a
data rate of 40 Gb/s, the storage capacitor would require
a capacitance which is lower than the parasitic
capacitances of an integrated transistor, so that noise,
leakage currents, and crosstalk would strongly degrade
the accuracy of the measurement or make it impossible.

It is one object of the present invention to provide a
method for measurement of optical or electrical signals
of an optical transmission system by which signal quality
can be measured even at very high data rates and an eye
diagram representation of the signal sequence can be
generated.

It is a further object of the present invention to
provide an eye diagram monitor which can be realized at
data rates of several Gb/s in a very simple manner, i. e.
with few devices.

BRIEF SUMMARY OF THE INVENTION

The above object can be achieved by a method as described
above wherein the probability that the value of the
signal sequence at a sampling time is above or below each
threshold value is measured, after a given period of time
the threshold value is changed and the probability that a
value of the signal sequence at a sampling time is above
or below a new threshold value is measured and the

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probability of the preceding threshold value is
subtracted from the probability of the current threshold
value.

In accordance with the method according to the present
invention the statistical properties of the measured
signal sequence are analyzed. The signal sequence usually
consists of a sequence of electrical signals, i. e.
voltages which represent the digital values „1" and „0"
of the transmitted data signal. Since the maximum number
of consecutive identical bits, i. e. sequences of „1"s
only or „0"s only, is limited by coding mechanisms, the
eye diagram has always the same shape.

The probability that a value of the signal sequence at a
sampling point is above a certain threshold value is
equal to the ratio of the number of samples of the signal
sequence which are above a certain threshold and the
total number of samples. E. g. for a given signal
sequence of which the minimum value is greater than zero,
the probability that a value of the signal sequence at a
sampling point is greater than the threshold value zero
is 100 %. Accordingly for a signal sequence with a
maximum value below 1 the probability that a value of the
signal sequence at a sampling point greater than 1 is 0
%.

In accordance with the present invention the
probabilities that a signal sequence has a value which is
in a threshold interval, i.e. between two threshold
values, are measured. The different threshold intervals
are each defined by two consecutive threshold values.
Thus, according to the present invention the probability

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distribution for different amplitudes of the signal
sequence at the sampling point is obtained. E. g. if the
first threshold value is 0 and the second threshold value
0.1 the probability that values of the signal sequence
are between 0 and 0.1 is obtained. In a further step the
new threshold value would be set to 0.2 and hence the
probability that values of the signal sequence are
between 0.1 and 0.2 is measured. If the threshold values
are increased step by step the probability of the
threshold value being between two thresholds can be
calculated from the difference of the probability of the
former threshold value and the probability of the current
threshold value.

According to a preferred embodiment of the present
invention the sampling time at which the signal
sequence is repeatedly sampled with a threshold value is
changed after a fixed or adjustable period of time.

According to a first alternative of this preferred
embodiment initially the probabilities of all threshold
values at one sampling time are measured and subsequently
the probabilities of all threshold values for a new
sampling time. In a second alternative of this embodiment
initially the probabilities for the first threshold value
at all sampling times are measured and afterwards for a
new threshold value the probabilities at all sampling
times are obtained.

With both alternatives the probability distribution of
the amplitude of signal sequence can be obtained not only
for a certain sampling time but also for an arbitrary
period of time. If the method according to this invention

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is applied to at least 1 complete period of the signal
sequence the eye diagram of the transmitted signal can be
reconstructed completely. With the first alternative the
eye diagram is constructed from different consecutive
vertical sections and with the second alternative it is
constructed from horizontal sections.

In accordance to the present invention the method can be
realized without any sample-and-hold circuit or analog-
to-digital converter, so that the disadvantages of these
devices which have been described above are omitted and
the measurement of eye diagrams is greatly simplified at
data rates of 10 Gb/s and above.

The present invention can be realized particularly simple
if the values of the signal sequence are fed to a
threshold decision circuit, the results from the
threshold decision circuit are counted by an event
counter and the results of the counter are stored in a
memory. If it is important to conduct the measurement
fast the values of the signal sequence can be fed
simultaneously to several decision circuits with
different thresholds so that the interval between the
highest and lowest expected value is subdivided in
different intervals according to the number of threshold
decision circuits.

According to the present invention the first threshold
value can be set to a value higher than the highest
expected signal level or lower than the lowest expected
signal value. In both cases this initial measurement can
also be used for control because in the first case the
probability that a signal value is higher than the
threshold value is 0 % and in the latter case the

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probability that a signal value is higher than the
threshold value is 100 %. After a certain number of
measurements or a certain period of time the threshold
value is in the first case decreased rsp. in the latter
case increased. This is done repeatedly until in the
first case the threshold value is smaller than the
smallest expected value rsp. in the second case the
threshold value is above the highest expected value.

Furthermore, the above object can be achieved by an eye
diagram monitor for generation of an eye diagram
representation of signal sequence as described above
wherein at least one counter is provided, the signal
sequence is fed to an input of the threshold decision
circuit, and the output of the threshold decision circuit
is connected to the input of the counter.

Thus the eye diagram monitor in accordance with the
present invention is characterized by the fact that no
sample-and-hold circuit or analog-to-digital converter is
required.

As a threshold decision circuit and/or counter a simple
flip-flop can be used. The eye diagram monitor according
to this invention does therefore not require measurement
of the signal amplitude but simply compares the values of
the signal sequence by means of a decision circuit with a
threshold and the result is counted by means of a
counter. The threshold decision circuit can also be
connected with an adjustable phase shifter.

Furthermore the method according to the present invention
rsp. the eye diagram monitor according to the present

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invention have the advantage that assessment of the
quality of the transmission path and a compensation of
distortion are possible even if the transmission data
rate is not or not exactly known. It is therefore not
required that the sampling rate is synchronous with the
transmission data rate. In fact an asynchronous
measurement is also possible because in each case a
probability distribution can be measured, i. e. an
amplitude histogram can be obtained. By means of the
asynchronously measured probability distribution the
quality of the eye diagram and thus the quality of the
transmission path can be estimated. In addition, with an
asynchronous measurement the transmission rate can be
identified by measuring - as described above - a vertical
section of the eye diagram which yields a periodic
amplitude histogram from which the period of the signal
sequence can be estimated if the sampling rate is known.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

In detail there is a multitude of possibilities to embody
or enhance the method according to this invention rsp.
the eye diagram monitor for generation of an eye diagram
according to this invention. In this respect we refer on
the one hand to those patent claims which are dependent
on claims 1 and 10 and on the other hand to the
description of a preferred embodiment in conjunction with
the drawing.

Fig. 1   shows an eye diagram of a signal sequence S,
Fig. 2   shows the probability distribution of signal
          sequence S at a first sampling point T_1 and to a
          second sampling point T_2 , and

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Fig. 3   shows a block diagram of the eye diagram monitor
           for generation of eye diagram of a signal
           sequence S.

Fig. 1 shows an eye diagram 1 of a signal sequence S
which is to be measured and obtained by means of the
method rsp. the eye diagram monitor according to the
present invention. An eye diagram 1 is the overlayed
representation of all bits of a signal sequence wherein
all bits representing a logical „1" are displayed as
positive square pulses with smoothed edges and all bits
representing a logical „0" are displayed as a negative
square pulse with smoothed edges. By overlaying of bits a
signal representation is obtained which reminds of the
shape of an eye. Through the overlay of a multitude of
bits and signal overshoot the eye diagram representation
is blurred.

On the basis of eye diagram 1 the expert can assess the
quality of the transmission system rsp. the received
signal sequence S. Signal degeneration in the
transmission path, e. g. distortion of the signal
sequence S through dispersion effects, leads for eye
diagram 1 to a „closing" of the eye. Since the vertical
opening H equals the distance between those bits that
represent logical „1"s and those bits that represent
logical „0"s, measurement of the vertical eye opening H
can be used for optimisation of the transmission path.
The lower H is the more difficult it is to distinguish
between the two states „1" and „0" of the signal
sequence.

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In accordance to the present invention the eye diagram 1
from Fig. 1 is obtained by measuring the probability
distribution 2 of signal sequence S at sampling time T_1 .
For this purpose the probability $W(SW_1)$ that the value of
signal sequence is above or below the respective
threshold value SW_1 is measured. After a given period of
time t_B which defines the length of the sampling period
the threshold SW_1 is changed and the probability $W(SW_2)$
that the value of signal sequence is above or below the
threshold value SW_2 is measured. Afterwards the
probability value $W(SW_1)$ of the first threshold SW_2 is
subtracted from the probability $W(SW_2)$ of the second
threshold SW_2 . Thereby the probability $W(DW)$ that a value
of the signal sequence at the sampling time T_1 is between
SW_2 and SW_1 is calculated.

If the first value SW_1 is chosen in such a way that it is
above the maximum expected value 'of the signal sequence
the above described method is repeated until the
threshold SW_n has reached a value which is below the
minimum expected value of signal sequence S. Accordingly
if the first value SW_1 is chosen in such a way that it is
below the minimum expected value of the signal sequence
the above described method is repeated until the
threshold SW_n has reached a value which is above the
maximum expected value of signal sequence S. As a result
one obtains the probability distribution 2 at sampling
time T_1 which is shown in Fig. 2a.

Fig. 2a and 2b show the probability distributions 2 at
two different sampling times T_1 and T_2. The horizontal
axis denotes the different thresholds SW whereas the
vertical axis denotes the probability $W(SW)$ that a

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sampled value occurs which is above threshold SW. It can
be seen at the probability distribution 2 according to
Fig. 2a that the probability distribution 2 has two
pronounced maxima when sampling time T_1 is approximately
in the center of the eye diagram. Both maxima correspond
to the logical values „1" and „0". If T_1 is clearly
outside the center then the probability distribution 2
according to Fig. 2b has more than two maxima. A well-
defined assignment which maximum represents the logical
„1" and the logical „0" is not possible any more.

If the probability distribution 2 is measured solely at
one sampling time T_1 the vertical eye opening only for
this sampling time can be obtained. Since the quality of
transmission can only be assessed based on the vertical
eye opening if the sampling point is chosen „right", i.
e. the sampling occurs in the center of the eye,
measurement of transmission quality based on 1 sampling
time and the vertical eye opening is of limited use.

Therefore the method in accordance with the invention has
to be applied not only for one sampling time T_1 but also
for a multitude of sampling times T_n so that by means of
calculation of all probability distributions 2 a
reconstruction of the complete eye diagram 1 is possible.
The resolution of eye diagram 1 can be adjusted by
choosing the sampling times T_n and the period of time t_B
in which sampling is performed.

Fig. 3 shows a block diagram of an eye diagram monitor in
accordance to the present invention which allows to
generate the eye diagram 1 by means of the method
described above. The eye diagram monitor has a threshold

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decision element 3, a storage element 4, and an analysis element 5.

In accordance with the present invention the eye diagram monitor is realized particularly simple but is nevertheless applicable for signal sequences S with very high data rates if it is constructed so that a counter 6 is provided wherein the counter 6 is arranged between the threshold decision element and the analysis element. The threshold decision element 3 exhibits an input 7 for the signal sequence and an output 8 which is connected with the input 9 of the counter 6.

In addition to that, in the embodiment shown in Fig. 3 there is an adder 10, a phase-shifter 11, and a second counter 12. The adder 10 is arranged at the input 7 of the threshold decision element 3 so that the input 7 of the threshold decision element 3 is not directly connected to the signal sequence S but to the sum of the signal sequence S and the adjustable DC voltage O. By means of the adder 10 in front of the threshold decision element 3 the adjustment of the thresholds SW can be accomplished by variation of the DC voltage O. The adder 10 can e. g. be realized with a series connection of an emitter follower and a resistor with an adjustable current. If the threshold is not changed in the threshold decision element 3 but indirectly by a modification of the DC voltage O which is added to the signal sequence S the threshold decision element 3 may have a fixed threshold. The threshold decision element 3 can then be realized by means of a simple flip-flop.

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With the arrangement of the phase shifter 11 between
clock signal C and input 13 of the threshold decision
element 3 the measurement of the probability distribution
2 of the signal sequence S at different sampling times T_n
can be realized. To the input of the phase shifter 11 the
clock signal C is fed wherein usually the frequency of
the clock signal C is chosen in such a way that the
transmission data rate is an integer multiple of the
frequency of the clock signal C. At a transmission data
rate of e. g. 40 Gb/s the frequency of the clock signal C
can be e. g. 1.25 GHz or 2.5 GHz.

The second counter 12 allows to measure the total number
of measurement cycles so that the result of the first
counter 6 can be put into relation to the result of the
second counter 12. Therefore the phase shifter 11 is
connected to the input of the second counter 12. Via the
second input of the first counter 6 and the second input
of the second counter 12 the counters can be reset by the
analysis element. Thus also the time period t_s can be
adjusted.

While the above description contains many specificities,
these should not be construed as limitations on the scope
of the invention, but rather as an exemplification of one
preferred embodiment thereof. Many other variations are
possible.

In detail there is a multitude of applications for the
method according to the present invention and the eye
diagram monitor according to the present invention.
Besides the equalization of signal sequences which was
described above the method is also suitable for „Quality

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of Service" measurements by which the transmission
quality of transmission paths are measured or tested. The
eye diagram monitor in accordance to this invention can
also be used e. g. in portable measurement equipment with
which the eye diagram of a signal sequence can be
displayed and with which the quality of the transmission
path can be assessed.

Accordingly, the scope of the invention should be
determined not by the embodiment illustrated, but by the
appended claims and their legal equivalents.